

Spectra and Biomarkers of Extrasolar Planets

NASA Grant NAG5-13045

Annual Reports 1 and 2

For the Period 1 April 2003 through 31 March 2005

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1. Introduction.

This is a combined annual report for the first two grant years of NAG5-13045, "Spectra and Biomarkers for Extrasolar Planets". The Principal Investigator (PI) is Wesley A. Traub at the Smithsonian Astrophysical Observatory (SAO). The Co-Investigators (CoIs) are Dennis Ebbets at Ball Aerospace, Daniel J. Jacob at Harvard University, Kenneth W. Jucks at SAO, James F. Kasting at Penn State University, Marc J. Kuchner at Princeton University, Sara Seager at Carnegie Institution of Washington, and Edwin L. Turner at Princeton University.

This grant was originally funded at about one-half of the requested funding level, so our first decision was to eliminate the post-doc position at the CfA, and use the funding for those CoIs who had requested support. However early in the grant period we found a potential post-doc, Dr. Lisa Kaltenegger, who would be perfect for much of the work proposed under this grant, and who would enable us to fulfill our originally proposed plan. We unanimously agreed that it would be in the best long-term interest of achieving our proposed research goals if we shifted the funding to support mainly a post-doctoral fellow. This would be at the expense of the summer salaries that had been previously allocated to several of the Co-Investigators. These CoIs graciously agreed to forgo their promised support, if we could persuade Lisa Kaltenegger to join the effort.

Beginning early in the first grant year we began to talk seriously with Lisa, trying to convince her to leave her position at ESTEC in Leiden, where she was working on the Darwin project, and come to Boston. In late spring of 2004 she agreed to make this move, after she finished her contract at ESTEC. On 6 January 2005 Lisa arrived in Boston, and began work the following day. As we had hoped, Lisa is now a valuable member of the team, and is working hard to carry out her part of the proposed research, as discussed in a later section below.

2. Work Accomplished.

During this period, and focussing on our work at SAO only, we have produced significant results in five areas: coronagraphs, color, Earthshine, near infrared, and meetings. These are discussed next.

2.1. We developed the theory of a new type of coronagraph for detecting and characterizing extrasolar planets. We wrote two papers, the first laying out the one-dimensional theory (Traub and Vanderbei 2003), and the second developing the two-dimensional theory, plus additional results (Vanderbei and Traub 2005). The basic concept is that of pupil mapping, whereby the uniform intensity of the incident starlight beam is converted into a Gaussian-shaped intensity profile, such that when focussed, the image of the star is itself a Gaussian-like profile, with extremely suppressed Airy rings. The great advantage of such a coronagraph is that it uses nearly all the collected light, and gives a tighter inner-working angle than any other design. Both of these features are helpful for detecting and spectrally characterizing an extrasolar planet.

2.2. We gained new insights into the role that simple color measurements can play in characterizing extrasolar planets (Traub 2003a-c). By comparing the colors of the planets in the Solar system, as measured in three wide-band filters, we find that the essential nature of the planet can be inferred. We can tell if it is rocky, or has an Earth-like cloud and atmosphere pattern, or a Venus-like cloud, or looks like the outer planets (methane-dominated). This information immediately allows us to infer the planet's albedo, and therefore its radius and temperature, all from visible reflection colors.

2.3. We proposed to observe the Earth from the South Pole, using Earthshine to mimic the process of characterizing an extrasolar planet (Traub et al. 2004). This proposal was submitted to the NSF, but was not funded. However we believe that this project is of great value to the TPF process, and would like to see it funded by NASA.

2.4. We analyzed observations of the Earth's reflection spectrum in the near-infrared, as a model of what we might see on an extrasolar planet (Turnbull et al. 2005). The observational data for this project were obtained by Nick Woolf and Maggie Turnbull, for part of Maggie's Ph.D. thesis work at the University of Arizona. We assisted her in the analysis of the data, following our previous analysis of similar earthshine data in the visible spectral range. A paper is being prepared. The interesting realization from this project was that the water vapor bands in the near-infrared are much stronger than in the visible, and that the near-infrared cloud reflection spectra carry information (ice or water) not available in the visible. This all suggests that it might be advantageous to have a near-infrared channel on TPF.

2.5. We did organizational work in the Terrestrial Planet Finder (TPF) program for several conferences in the US and Europe. We were on the organizational committees of the Darwin-TPF meeting in Heidelberg in 2003, the joint US-Europe coronagraph conference in Leiden in 2004, the SPIE meeting on interferometry in Glasgow in 2004, and the ongoing series of TPF SWG meetings in 2003-2004. For the latter we especially worked to refine the Science Requirements Document for TPF during much of 2003-2004, for both the visible and infrared versions of TPF.

3. Work to be Performed During the Next Reporting Periods.

Focussing on the work we plan to do during the coming grant years, we have the following projects outlined for Dr. Kaltenegger to address, in collaboration with the PI and CoIs. In general, she will conduct research on the spectra and biomarkers of extrasolar planets, and connect this research with future space missions. In particular, she will develop visible and infrared model spectra of extrasolar planets, develop diagnostic tools to characterize these planets, critically examine the planet characteristics that can be measured or inferred using these tools, validate these methods by comparison with the spectra of Solar System planets, and connect these tools with planned ground- and space-based observations.

At present Dr. Kaltenegger will be participating actively in the Aspen conference on extrasolar planets in February 2005, the astrobiology conference in Boulder in spring 2005, and the conference on protostars and planets in Hawaii in fall 2005. She has already contributed to our work on calculating Earthshine spectra in the near infrared, and is quickly becoming familiar with our spectral calculation programs. In short, she is rapidly integrating herself into our work. Clearly our decision to reprogram the funds under this grant was the right decision.

4. Funding Status.

By promising Lisa Kaltenegger that her first-year salary and related expenses was assured, we have fully committed the balance of the first year of funding under this grant. Some of the first-year funding had already been expended pursuing the 5 activities outlined above. Thus at present we need to have the second year of funding put in place, and will so request.

5. References.

Two-Mirror Apodization for High-Contrast Imaging (W.A. Traub and R.J. Vanderbei) *Astrophysical Journal* **599**, pp. 695-701, 2003

Extrasolar Planets and Biomarkers (W.A. Traub) *ASP Conference Series* **291**, pp. 117-124, K.R. Sembach, J.C. Blades, G.D. Illingworth, R.C. Kennicutt, eds., (2003a)

The Colors of Extrasolar Planets (W.A. Traub) *ASP Conference Series* **294**, pp. 595-602, D. Deming and S. Seager, eds., (2003b)

Extrasolar Planet Characteristics in the Visible Wavelength Range (W.A. Traub) *ESA conference, Toward Other Earths, ESA SP-539* pp. 231-239, (2003c)

An Optical/UV Space Coronagraph Concept for the Terrestrial Planet Finder (N. J. Kasdin, R. A. Brown, C. J. Burrows, S. Kilsten, M. Kuchner, M. Littman, M. C. Noecker, S. Seager, D. N. Spergel, E.L. Turner, W. A. Traub, R. J. Vanderbei, and R. A. Woodruff) *Advances in Space Research* **34**, pp. 625-630, 2004

Pupil Mapping in 2-D for High-Contrast Imaging, (R.J. Vanderbei and W.A. Traub)
Astrophysical Journal, submitted, 2004

The South Pole Earthshine Project (W.A. Traub, P. Goode, S.D. Kilston, S. Seager, A.A. Stark, K.W. Jucks, P.A. Schuller, M. Turnbull, E.L. Turner), proposal submitted to the NSF June, 2004.

Near-Infrared Earthshine Observations (M. Turnbull et al.), in preparation, 2005.